Ilorin Journal of Science
Volume 9, Number 2, 2022, pp. 137 – 161 (Printed in Nigeria)
ISSN: 2408 – 4840 © 2022 Faculty of Physical Sciences, University of Ilorin
https://doi.org/10.54908/iljs.2022.09.02.003

ILORIN
JOURNAL OF SCEINCE

ILJS-22-010

Geophysical Assessment of Leachate Migration and Aquifer Protective Capacity of Cassidy Dumpsite, Ojo, Lagos State, Nigeria

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Abstract

Vertical electrical Station (VES) prospecting and two-dimensional (2d) resistivity imaging were used to assess the leachate displacement and aquifer protection potential at the Cassidy landfill in Lagos, Nigeria. Twenty–six VES and four 2D resistivity profiles were acquired. Leachate contamination was evaluated using the longitudinal conductivity (S) parameter derived from the apparent resistivity and thickness values. Analysis of VES and 2D resistivity data was done using WinResist and DIPROFWIN Software respectively. Three to six geological layers derived from VES data include topsoil, clay, sand, clay-sand, sandy clay, and clay/leachate. The 2D resistivity configuration revealed that the lateral and vertical subsurface resistivity values were spanning from 6 Ωm to 138 Ωm. Three different aquifer protection potential zones were diagnosed with protection capacities of 36%, 52%, and 12%, respectively. Zones with adequate aquifer protection have good damping properties for contaminated liquids. Leachate Infiltration varies between 4.8 m and 17.0 m depth. Protection capacity should not be neglected in planning areas for groundwater exploration, and zones with low vulnerability and moderate or high groundwater protection potential should be optimally used

Keyword: Vertical Electrical Sounding, Resistivity imaging, Leachate Migration, Aquifer Protective Capacity

1. Introduction

Municipal solid waste (MSW) disposal is generally an urban problem and is of global concern, particularly in developing countries that were characterized with poverty, population growth and urban drift, couple with under-funding by governments, which lead to poor management of the wastes (Doan, 1998; Aderemi et al., 2011; Hossain et al., 2014).

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Landfilling has being a simple and most cost-effective method of disposing wastes in both developing and developed nations (Ogunmakinde et al., 2019). However, in most developed nations there has been a reduction in the number of landfills as well as the amount of MSW landfilled over the years. According to USEPA (2008), the total amount of MSW going to landfills in the United States dropped by about 5 million tons, from 142.3 million tons in 1990 to 137.2 million tons in 2007. The number of landfills in the United States also declined steadily from 7,924 in 1988 to 1,754 in 2007 (USEPA, 2008).

Solid waste management has been identified as one of the problems confronting both the Federal and State government environmental protection agencies in Nigeria. The amount of solid waste being generated is higher than the capacity that the agencies can cope with, considering the available financial and technical resources. Inefficient and insufficient coverage of the collection system as well as improper disposal of solid waste are affecting solid waste management greatly in Nigeria. These result in indiscriminate dumping of the wastes in many municipalities.

Landfill in an uncontrolled site (dumpsite) poses a considerable threat of lives to the people residing near the site and to the soil within the environment; as it has been identified as a major pollutant factor to groundwater resources and agricultural products (Fatta *et al.,* 1999). Taylor and Allen (2006) submitted that landfills are major factors responsible for pollution of groundwater.

Generation of leachate, which is the liquid produced from the decomposition of waste and infiltration of rainwater in the landfill (Mukherjee et al., 2015) occurs when sufficient moisture, enough to initiate a liquid flow enters a landfill of refuse and dissolves the contaminants in the landfill into the liquid phase. This liquid may leave the disposal site, enter the underlying hydrogeology system and make the groundwater not potable. This process is more pronounced during rainy season and it leads to increase in groundwater pollution.

Leachate derived from a landfill depends on the type and nature of the waste deposited. The likelihood of disposing of wastes polluting groundwater is the characteristic of the unsaturated region and the attenuation ability of the underlying site (Lee and Jones, 1993). The attenuation capacity of the underlying site is otherwise referred to as the overburden material or aquifer protective capacity, which determines the level of aquifer contamination to vulnerability by leachate.

Aquifer vulnerability describes the susceptibility of groundwater quality to pollutant loading (Edet, 2013), which is a function of the natural properties of the aquifer. The type of geologic material covering the aquifer determines the protection capacity. The increase in infiltration rate lead to increase in the vulnerability of an aquifer; the hydraulic conductivity and the thickness of the geologic layer covering the aquifer control the infiltration rate (Van Stempvoort et al., 1992; Ameloko and Ayolabi, 2018). Aquifers that have sand as covering materials are prone to vulnerability than clay. The clay is less vulnerable compare to sand because it is less porous.

Water is vital for the survival of life (plant or animal). Groundwater has been identified to be chief reservoir of drinkable water in the world (Zekster and Everett, 2004).

The health and well-being of the population depend on the abundance, adequate supply, potable and accessibility of this natural resource. The harms posed to groundwater resources by non-controlled landfills are very detrimental based on the knowledge of leachate percolation to the subsurface region, which results in water pollution. Therefore, investigating level of groundwater pollution and a need to preserve quality of groundwater resources becomes necessary because of various degrees of water-borne diseases such as diarrhea, typhoid, cholera, dysentery, and skin cancer. These diseases occur worldwide causing over 4% of all deaths and 5% of health loss to disability **(**Taylor and Allen, 2006).

Geophysical methods, especially the electrical resistivity technique which is non-invasive and relatively cheap technique (Sikander *et al*., 2010) have found application in groundwater exploration and also in landfill-related studies (Loke, 2011; Yang and Joshi, 2014).

This study assessed the level of leachate migration and evaluates the protective capacity of near-surface materials overlying the aquifer at Cassidy, in Ojo Local Government area of Lagos State using integrated electrical resistivity geophysical methods. The outcome of the study is hoped to contribute to the planning and management of the groundwater resources.

2. Geology and location of the study area

The study area, Cassidy, is located in Ojo Local Government Area of Lagos State, Nigeria (Figure 1).

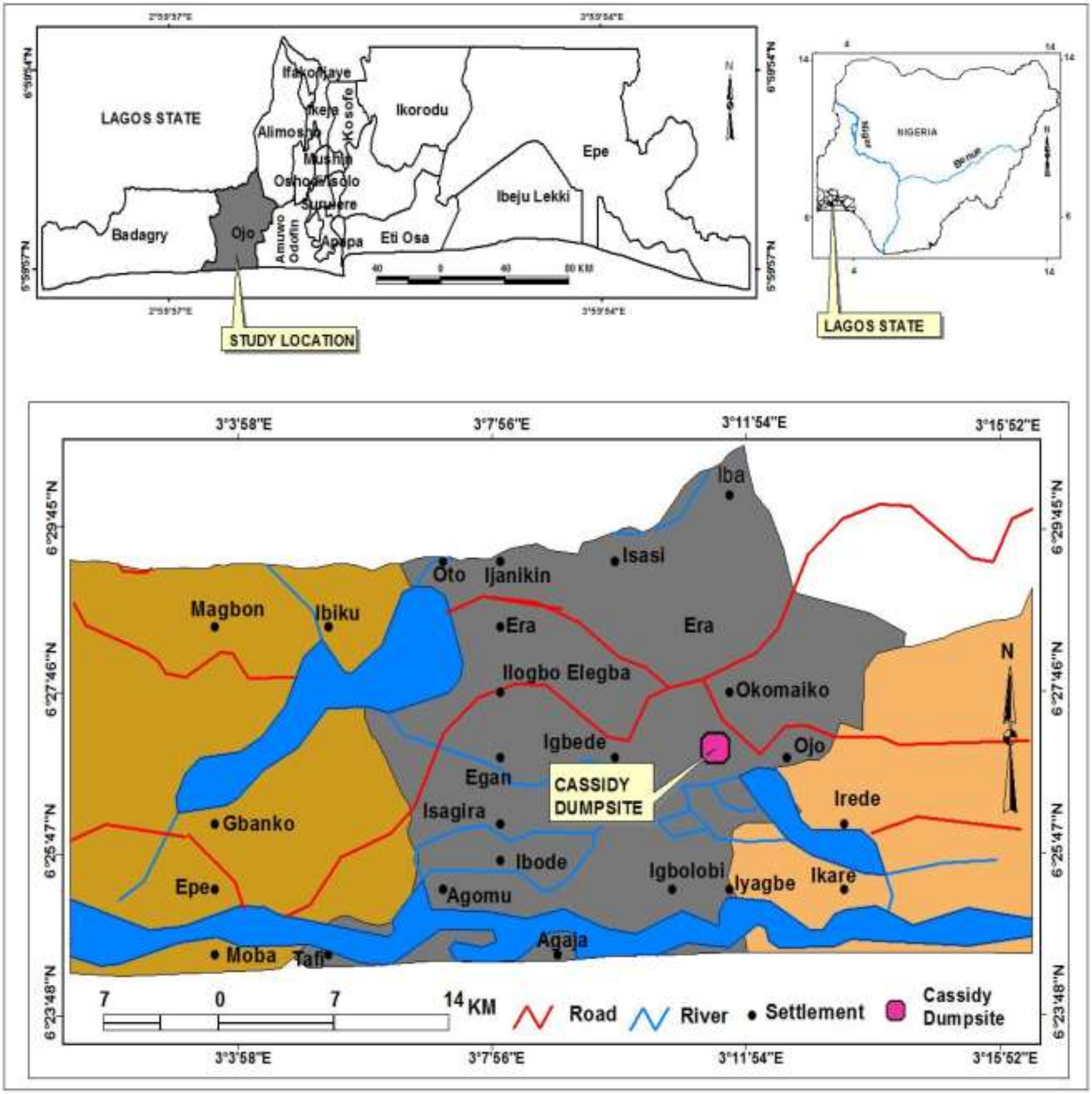

Figure 1: Location of the study location.

The geological setting of the study area indicates that it lies entirely within the vast Dahomey Basin. Coastal and lagoon deposits of new sediments underlie the area. The littoral belt varies from approximately 8 km near the border with the Republic of Benin to 24 km towards the eastern end of Lagos Lagoon (Nton, 2001). The site also consists of clayey sediments, loose sand, and soil, with varying proportions of vegetative on the flanks of the coastal area.

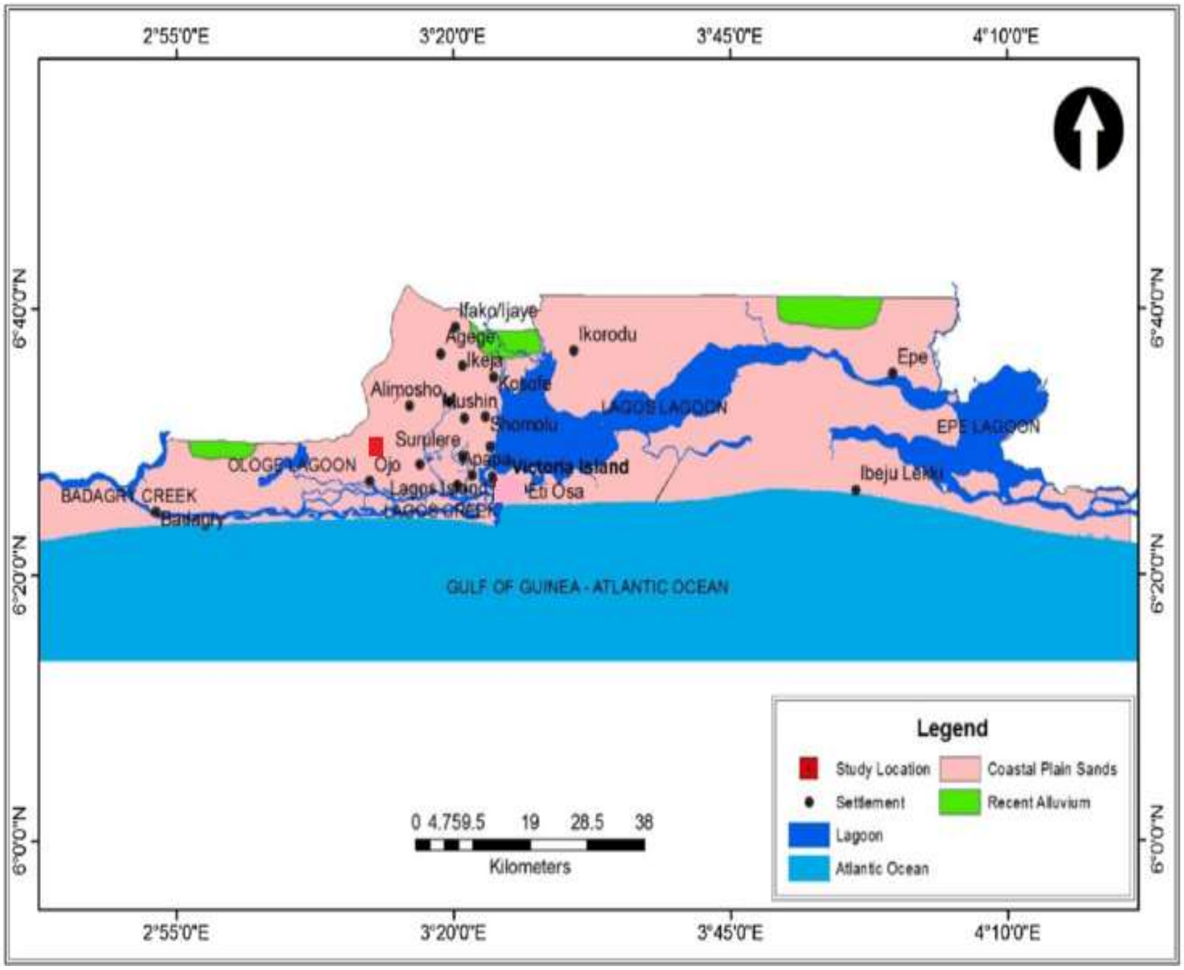

Figure 2: Geology of the study area

3. Materials and Methods

The electrodes were driven into the ground with the aid of a hammer and the electrode cables were clipped to the electrode using crocodile clips. The cables were connected to the PASI 16GL Terrameter powered by a 12-Volt battery, placed at the mid-point, and shielded with an umbrella to prevent sun rays. Readings were taken with specified electrode spacing depending on electrode array types. The coordinates of each of the traverse lines and specific points for the VES were taken with a GPS (Global Positioning System).

Twenty-five VES stations were acquired at different points. The geodetic system of coordinates was obtained using Garmin 12 GPS. The current electrode separation (AB) was varied from 2 to 120 m. Three to nine VES points were carried out on each 2-D electrical imaging profile, to integrate the VES and the 2D.

The Wenner array electrode was used for the 2D resistivity imaging data acquisition. Measurements were made with four electrodes at step of 5 m interval; 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 m to cover four traverses within a distance of 180 m (Figure 3).

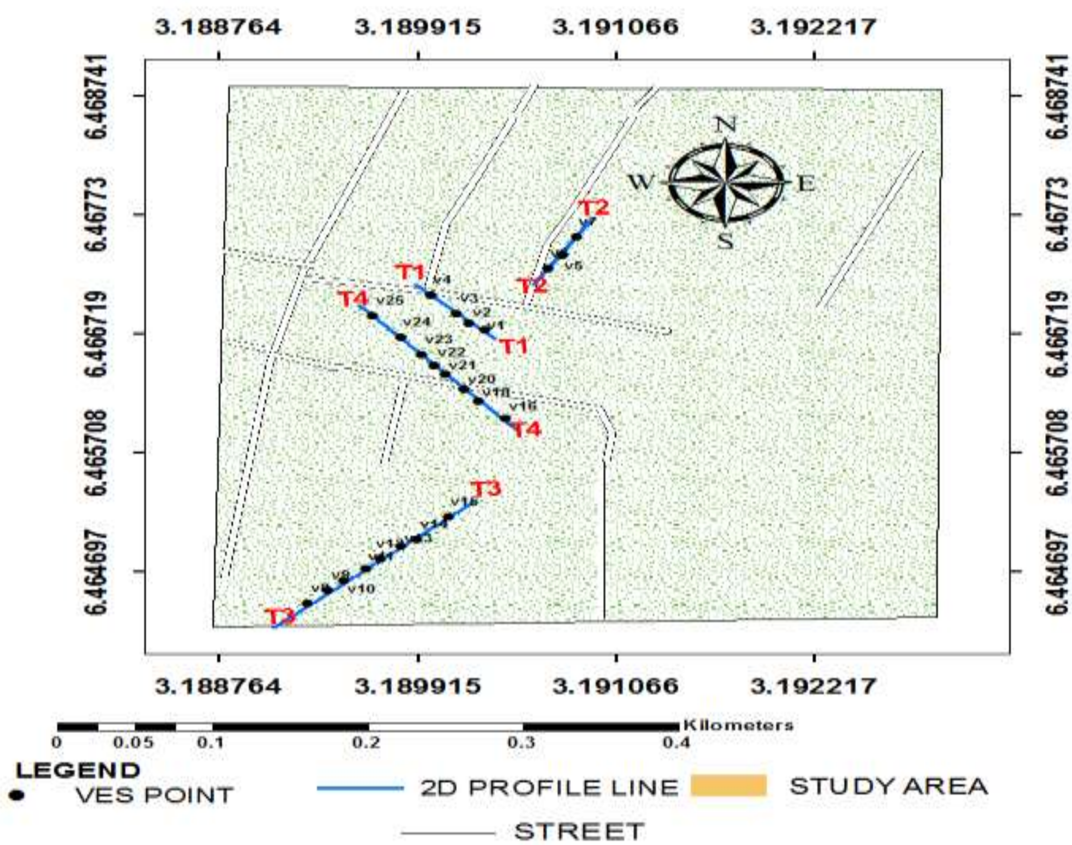

Figure 3: Base map survey layout showing the VES stations and lines of transects for the ERT profiles

The inversion of the 2D apparent resistivity data was done using DIPROFWIN software, which produced pseudo section and 2D resistivity structure and also filtered out the noise.

The Diprofwin program recompenses the bulk data into horizontal and vertical rectangular blocks, with every field reveal some information. The calculated resistivity of each block was used to produce apparent resistivity pseudo section. The distinction between measured and real resistivity gives the inversion form which represents the geology of the observed region.

The obtained apparent resistivity data were both quantitatively and qualitatively processed. The partial curve matching technique was employed for quantitative interpretation (Bhattacharya and Patra, 1968). The results of the VES curves received from the partial curve matching were used to constrain the interpretation by the computer using inversion software program called WinResist software program. This reduces the overestimation of depths in the curve matching. The result of the computer iteration indicates the quantitative analysis to recognize the resistivity, thickness, and depth.

The qualitative interpretation of the depth sounding curves was done based on individual geo-electric features on the number of layers represented by the four different types of the auxiliary curves (A, H, okay, and Q) and additionally from the profiles and maps inspection for patterns anomaly signatures which can be diagnostic of the target.

Evaluation of Aquifer Protective Capacity

First-order geo-electric parameters obtained from the iteration was employed to develop the second-order geo-electric parameters or the Dar Zarrouk parameters (Aladesanmi et al., 2014). The second-order parameter of interest is the longitudinal unit conductance (Si). Longitudinal conductance is derived using equation (1).

$$S = \sum_{i=1}^{n} \left(\frac{hi}{\rho i}\right) \text{ for n layers.} \qquad (1)$$

The longitudinal unit conductance values were employed to rate protective capacity from poor to excellent (Table 1).

Table 1: Modified longitudinal conductance/protective capacity rating (Henriet, 1976; Oladapo et al., 2004)

Longitudinal conductance (mhos)	Protective capacity rating
>10	Excellent
5 – 10	Very Good
0.7 - 4.9	Good
0.2 - 0.69	Moderate
0.1 - 0.19	Weak
<0.1	Poor

4. Results and Discussion

The data involved in the electrical resistivity survey includes twenty-five VES. The summary of the interpreted VES results with inferred lithology is presented in Table 2.

Table 2: VES Summary

VES No	Layers	Resistivity (Ωm)	Thickness (M)	Depth (M)	Curve Type	Inferred Lithology
1	1	106.3	0.5	0.5	KHK	Topsoil
	2	115.6	1.2	1.7		Sand
	3	26.1	3.0	4.7	$\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5$	Clay
	4	200.1	17.6	22.5		Sand
	5	16.8	---	---		Clay
2	1	258.6	0.8	0.8	HA	Topsoil
	2	44.6	6.5	7.3		Clay
	3	161.6	14.8	22.1	$\rho_1 > \rho_2 < \rho_3 < \rho_4$	Sand
	4	174.1	---	---		Sand
3	1	31.1	0.9	0.9	AA	Topsoil
	2	46.9	1.7	2.6		Clay
	3	70.2	14.9	17.5	$\rho_1 < \rho_2 < \rho_3 < \rho_4$	Clayey Sand
	4	137.0	---	---		Sand
4	1	13.3	0.9	0.9	AA	Topsoil
	2	38.7	1.8	2.7		Clay
	3	94.1	6.0	8.6	$\rho_1 < \rho_2 < \rho_3 < \rho_4$	Clayey Sand
	4	133.3	---	--		Sand
5	1	25.5	1.0	1.0	KHA	Topsoil
	2	61.7	0.7	1.8		Clayey Sand
	3	15.0	0.5	2.2	$\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5$	Clay
	4	25.5	9.0	11.2		Clay
	5	278.5	---	---		Sand
6	1	31.6	0.8	0.8	AA	Topsoil
	2	35.5	1.6	2.4		Clay
	3	85.1	8.8	11.2	$\rho_1 < \rho_2 < \rho_3 < \rho_4$	Clayey Sand
	4	160.9	---	---		Sand
7	1	16.6	1.0	1.0	AK	Topsoil
	2	83.2	2.3	3.3		Clayey Sand
	3	345.2	12.2	15.5	$\rho_1 < \rho_2 < \rho_3 > \rho_4$	Sand
	4	62.4	---	---		Sandy Clay
8	1	62.2	0.9	0.9	HA	Topsoil
	2	48.1	3.3	4.2		Clay
	3	78.2	7.0	11.2	$\rho_1 > \rho_2 < \rho_3 < \rho_4$	Clayey Sand
	4	434.8	---	---		Sand
9	1	76.8	0.9	0.9	HK	Topsoil
	2	34.0	3.7	4.5		Clay
	3	404.9	22.4	27.0	$\rho_1 > \rho_2 < \rho_3 > \rho_4$	Sand
	4	19.8	---	---		Clay
10	1	80.7	0.9	0.9	QH	Topsoil
	2	40.7	1.3	2.2		Clay
	3	29.2	9.5	11.7		Clay

	4	212.2	---	---	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	Sand
11	1	75.6	0.3	0.3	QHK	Topsoil
	2	59.4	2.5	2.8		Sandy Clay
	3	9.4	4.4	7.2	$\rho_1 > \rho_2 > \rho_3 < \rho_4 > \rho_5$	Clay/Leachate
	4	214.6	8.4	15.5		Sand
	5	7.4	---	---		Clay/Leachate
12	1	39.2	0.8	0.8	KQH	Topsoil
	2	116.4	0.6	1.5		Sand
	3	24.7	5.5	7.0	$\rho_1 < \rho_2 > \rho_3 > \rho_4 < \rho_5$	Clay
	4	6.7	10.0	17.0		Clay/Leachate
	5	67.8	---	---		Clayey Sand
13	1	53.7	0.5	0.5	KHA	Topsoil
	2	59.3	4.2	4.8		Clayey Sand
	3	3.0	1.1	5.8	$\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5$	Clay/Leachate
	4	19.1	29.8	35.7		Clay
	5	68.6	---	---		Clayey Sand
14	1	41.4	0.9	0.9	KQHK	Topsoil
	2	172.0	0.6	1.5		Sand
	3	152.9	3.1	4.6	$\rho_1 < \rho_2 > \rho_3 > \rho_4 < \rho_5 > \rho_6$	Sand
	4	50.9	12.4	17.0		Sandy Clay
	5	451.7	15.3	32.3		Sand
	6	21.3	---	---		Clay
15	1	42.4	0.9	0.9	AK	Topsoil
	2	406.5	2.8	3.6		Sand
	3	538.9	12.3	15.9	$\rho_1 < \rho_2 < \rho_3 > \rho_4$	Sand
	4	150.4	---	---		Sandy Clay
	1	83.0	0.7	0.7	QH	Topsoil
	2	54.9	3.7	4.4		Sandy Clay
16	3	46.7	17.3	21.8	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	Clay
	4	237.0	---	---		Sand
	1	104.3	0.8	0.8	HA	Topsoil
	2	48.8	2.0	2.9		Clay
17	3	54.6	12.0	14.9	$\rho_1 < \rho_2 < \rho_3 > \rho_4$	Clayey Sand
	4	116.6	---	---		Sand
	1	176.2	0.6	0.4	QH	Topsoil
	2	97.5	2.0	2.5		Sandy Clay
18	3	9.7	2.0	4.5	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	Clay/Leachate
	4	104.5	---	---		Sand
	1	53.9	1.1	1.1	KH	Topsoil
	2	93.8	1.4	2.5		Clayey Sand
19	3	19.7	5.5	8.0	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	Clay
	4	116.5	---	---		Sand
	1	127.9	0.9	0.9	QH	Topsoil
	2	65.7	1.9	2.8		Sandy Clay
20	3	28.7	11.1	14.0	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	Clay
	4	139.6	---	---		Sand
21	1	48.1	0.7	0.7	A	Topsoil
	2	56.1	39.8	40.5		Clayey Sand
	3	149.0	---	---	$\rho_1 < \rho_2 < \rho_3$	Sand
22	1	63.0	0.8	0.8		Topsoil
	2	116.8	2.7	3.4		Sand

	3	378.2	28.3	31.7	AK	Sand
	4	70.6	---	---	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	Sandy Clay
23	1	71.7	0.7	0.7	HAK	Topsoil
	2	39.3	2.3	3.0		Clay
	3	255.4	3.9	6.9	$\rho_1 > \rho_2 < \rho_3 < \rho_4 > \rho_5$	Sand
	4	379.3	22.0	28.9		Sand
	5	78.0	----	---		Sandy Clay
24	1	120.0	0.4	0.4	HK	Topsoil
	2	26.9	3.2	3.7		Clay
	3	372.1	10.0	13.7	$\rho_1 > \rho_2 < \rho_3 > \rho_4$	Sand
	4	20.7	---	---		Clay
25	1	37.8	0.6	0.6	AKH	Topsoil
	2	113.1	2.2	2.8		Sand
	3	221.1	9.3	12.1	$\rho_1 < \rho_2 < \rho_3 > \rho_4 < \rho_5$	Sand
	4	40.3	17.8	29.9		Clay
	5	172.4	---	---		Sand

Geo-electric section

The geo-electric sections (Figures 4a to 4d) of the various VES stations; VES 1 to 4, VES 5 to 7, VES 8 to 15, and VES 16 to 25 were constructed to depict different geo-electric layers profiles (Abdulaziz and Faid, 2017); A - A', B - B', C – C' and D - D' respectively. The layers of geo-electric section for the profile are in the range of 4 to 6. The resistivity values of the topsoil ranged from 13.3 Ωm to 258.6 Ωm and layer thickness of 0.1 to 1.1 m. The thickness of topsoil vary with each profile but more extensive in profile D - D'. Sand cover appears in all the profile, though at different layer but it dominates in all the profile. Clay and clayey sand present in all the profiles. VES 1 to 6, 8 and 10 are having representative of clay. The third geo-electric layer in VES 1 is dominated with clay having layer thickness value of 3.0 m. The fourth horizon in VES 24 and 25 are of clay with layer thickness of 17.8 m. The second layers of VES 12, 14, and 15 in C – C' are representatives of sand characterized by resistivity values ranging from 116.4 to 406.5 Ωm and layer thickness of 0.6 to 2.8 m. The sand at this vicinity represents an aquifer unit where groundwater could be sourced. Clay/leachate with resistivity values starting from 3.0 to 9.4 Ωm were present in third layer of VES 11 and 13 with layer thickness of 1.1 to 4.4 m also clay/leachate are found in VES 12 with a resistivity value of 6.7 Ωm and layer thickness of 10.0 m. The 5th substratum layer below VES 11 is diagnostic of clay/leachate with a resistivity value of 7.4 Ωm and no layer thickness, which indicates cutting-edge termination within the location.

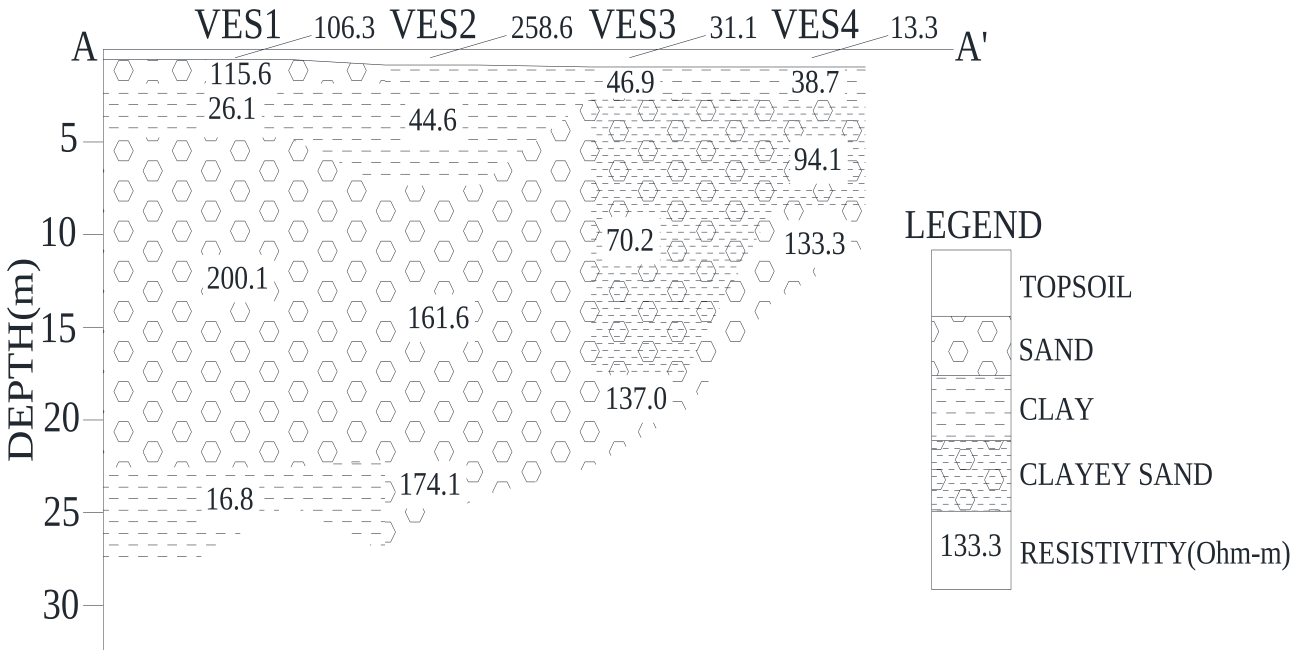

Figure 4a: Geo-electric Section for VES 1, 2, 3 and 4

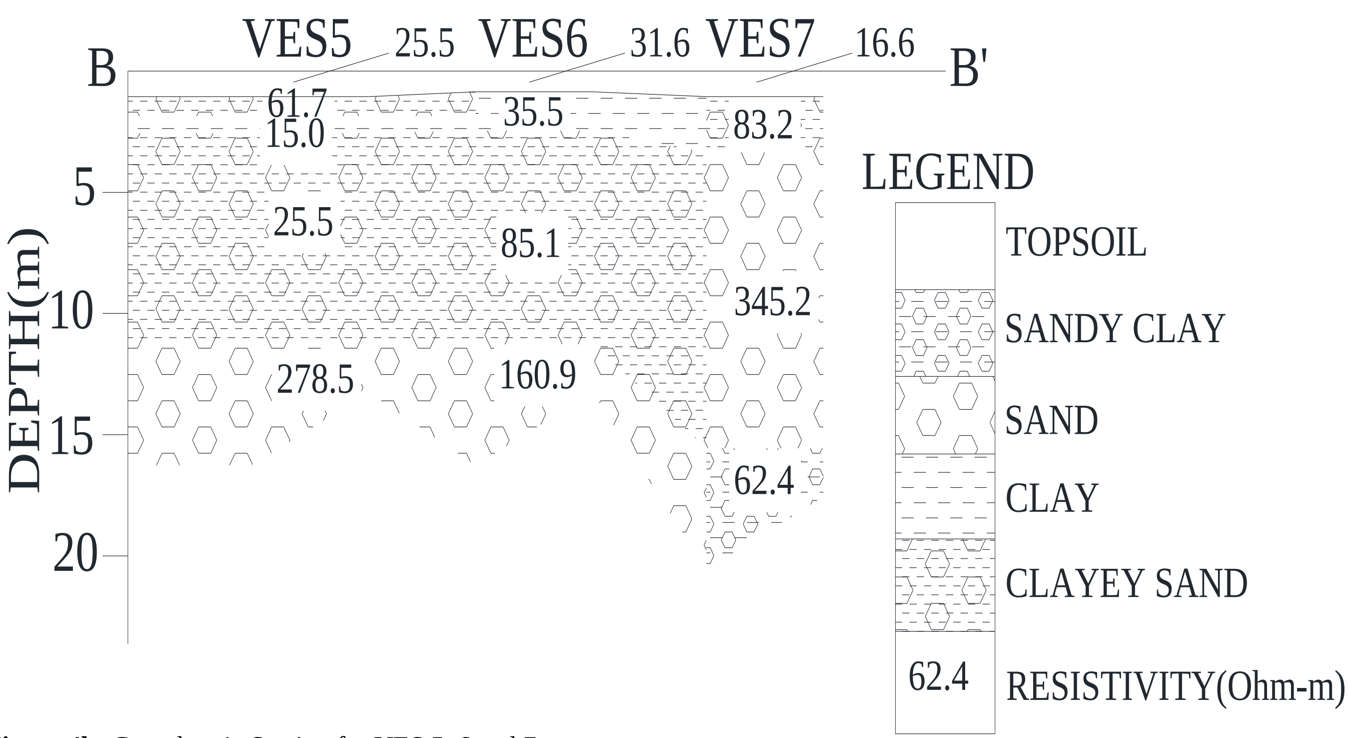

Figure 4b: Geo-electric Section for VES 5, 6 and 7

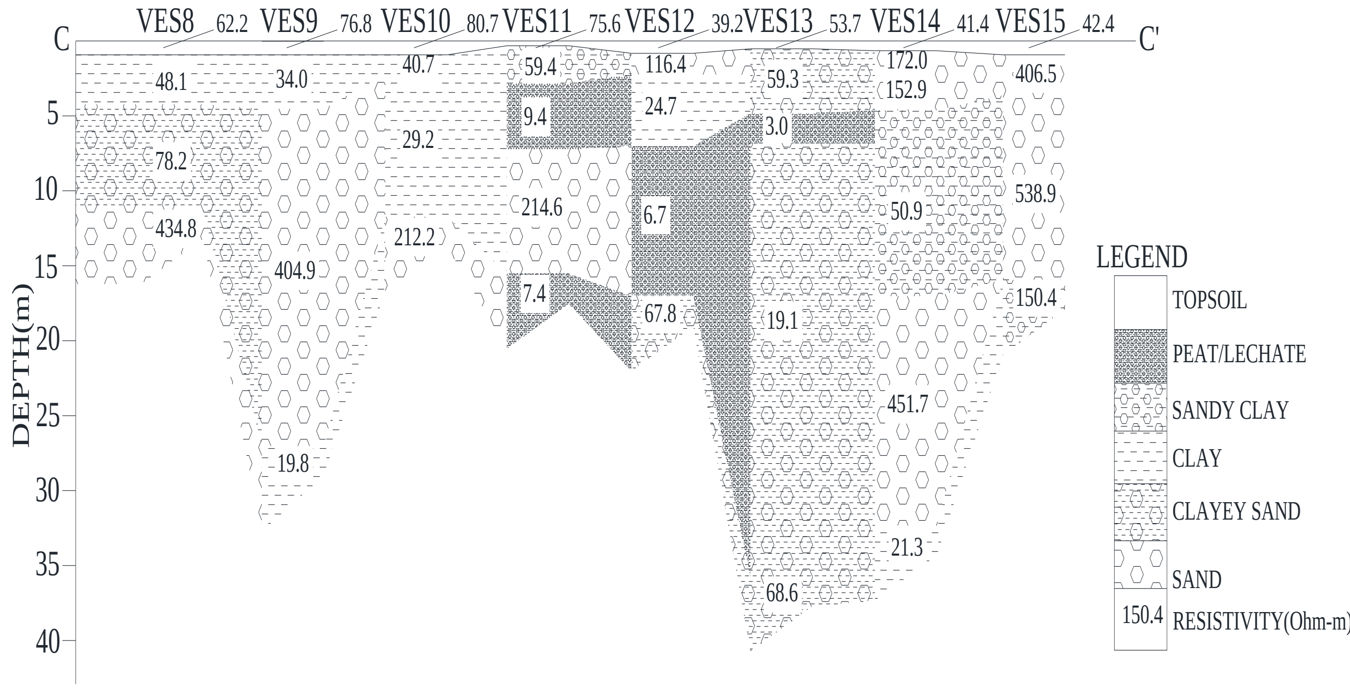

Figure 4c: Geo-electric Section for VES 8, 9, 10 11, 12, 13, 14, and 15

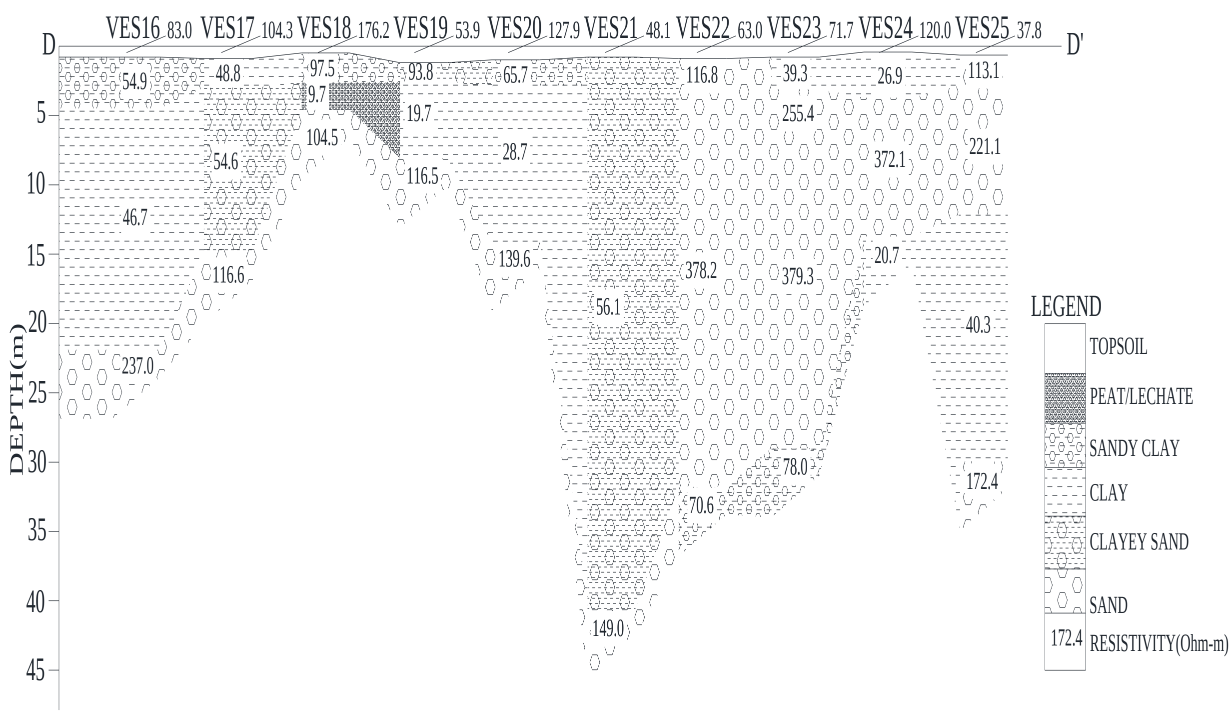

Figure 4d: Geo-electric Section for VES 16, 17, 18, 19, 20, 21, 22, 23, 24 and 25

Results of 2D Electrical Resistivity Imaging

The results of the Inverted 2D Resistivity Structure were presented in Figures 5(a - d). The horizontal scale on the section is the lateral distance while the vertical scale is the depth, both in meters. A minimum to a maximum spread of 130 to 180 m was modeled with the corresponding depth of 30 to 50 m investigated on all the profiles.

2D Resistivity Section along Traverse One

A total spread of 180 m was surveyed and a depth of 50 m was probed with resistivity values ranging from 17 to 92 Ωm as shown in Figure 5a. The VES 1, 2, 3 and 4 were along the 2D profile at lateral distance of 70, 90, 110 and 125 m respectively. The lateral distance of 0 - 30 m along the profile indicates low resistivity value of <17 Ωm, depicting the presence of leachate from the ground surface to a depth of 10 m, which could be interpreted as topsoil contamination. The lateral distance of 30 m to 45 m, from the ground surface to a depth of 15 m is indicative of clay/leachate and clay, having resistivity value within the range of 25 to 40 Ωm. At a lateral distance of 45 to 70 m with depth from the ground surface to 20 m are clay and clayey sand having resistivity values > 40 to 77 Ωm. At a lateral distance of 70 to 90 m, clay/leachate is depicted, which is from a depth of 0 to 15 m with a resistivity value of < 40 Ωm, while further depth from 15 to 25 m has a resistivity value in the range of 45 to 93 Ωm indicating clay and clayey sand. Along the profile, at a lateral distance of 90 to 180 m and a depth of 10 m from the ground surface, is indicative of clay and clayey sand having resistivity value in the range of 31 to 93 Ωm. At a distance of 140 to 170 m are clay and clayey sand but from a depth of 10 to 50m. Leachate is distinctive at the depth of 10 to 20 m at lateral distance of 170 to 180 m across the profile having resistivity value of <18 Ωm. The high resistivity value >100 Ωm indicates sandy clay and sand.

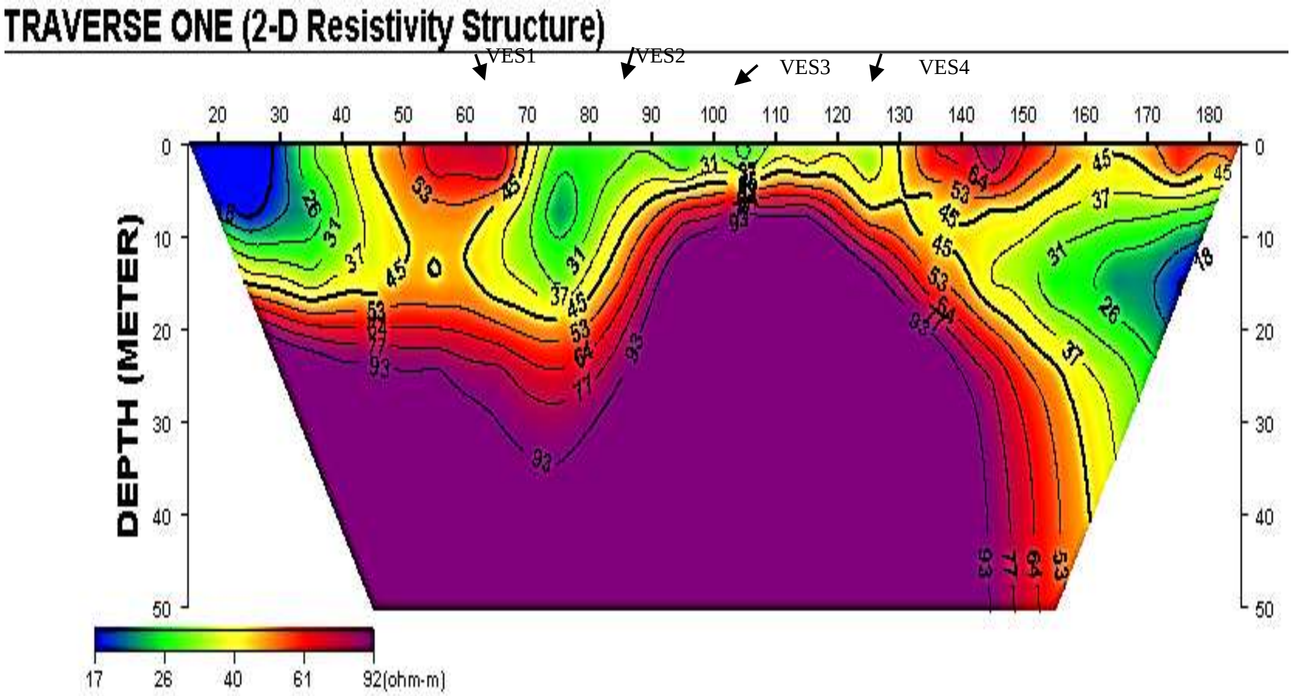

Figure 5a: 2D Resistivity Structure (Traverse One)

2D Resistivity Section along Traverse Two

A total spread of 130 m was surveyed and a depth of 30 m was probed with resistivity values ranging from 9 to 94 Ωm (Figure 5b). The VES 5, 6, and 7 were along the 2D profile at lateral distance of 50, 65, and 80 m respectively. The lateral distance from 0 to 40 m along the profile shows resistivity value in the range of 29 to 94 Ωm which is indicative of clay and clayey sand to a depth of 10 m from the ground surface. At a lateral distance of 40 to 130 m, within depth from 5 to 10 m across the profile, shows resistivity value in the range of 15 to 94 Ωm revealing clay/leachate, clay, and clayey sand. There is distinct evidence of contamination of the topsoil by leachate as shown by a low resistivity value <10 Ωm along the profile, which is between lateral distance of 52 and 70 m, and has subsequent occurrence between the distance of 85 and 130 m, from the surface to an approximate depth of 4 m. The depth from 10 to 30 m across the profile to deeper subsurface, signifies region with high resistive values >100 Ωm indicating sandy clay and sand.

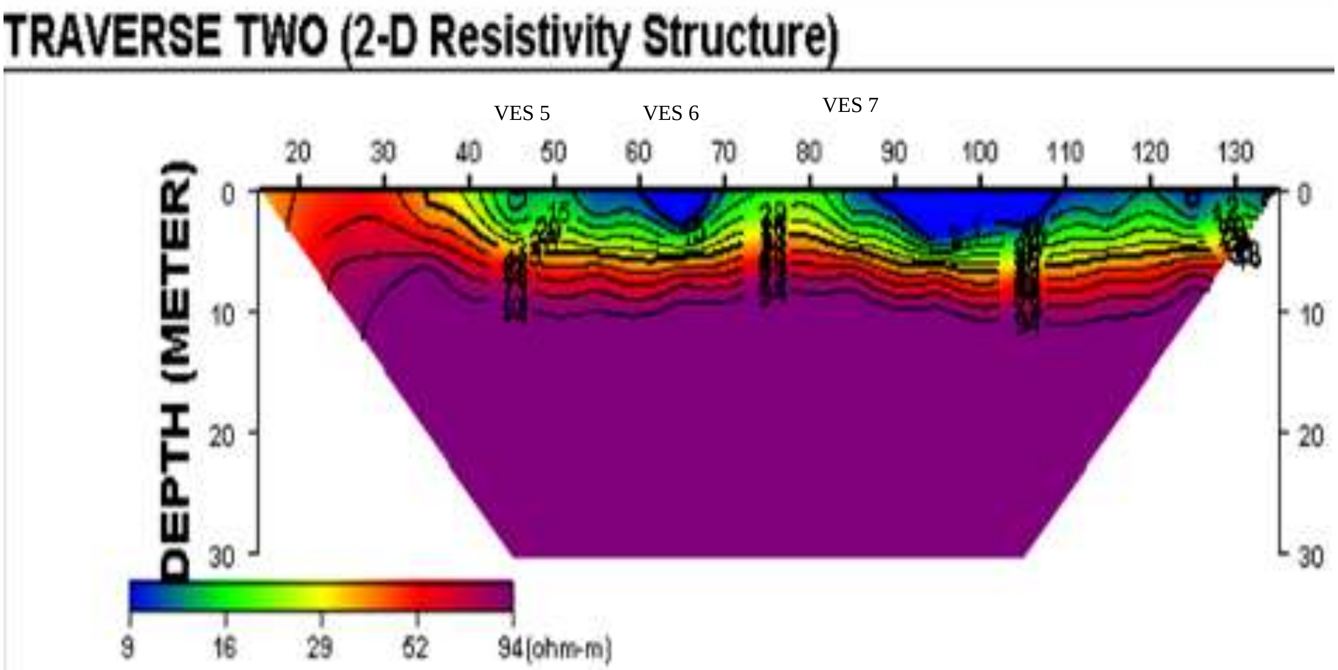

Figure 5b: 2D Resistivity Structure (Traverse Two)

2D Resistivity Section along Traverse Three

A total spread of 180 m was surveyed and a depth of 50 m was probed with resistivity values ranging from 6 to 53 Ωm (Figure 6c). The VES 8, 9, 10, 11, 12, 13, 14, 15, and 16 were along the 2D profile at lateral distances of 50, 65, 80, 95, 110, 125, 140, 155 and 160 m respectively. At lateral distances of 0 to 40 m with a depth of 0 to 40 m is indicative of clay/leachate, clay and clayey sand having resistivity values of >11 to 53 Ωm. While distances of 40 to 100 m having resistivity values of 11 to 53 Ωm, at depth of 0 to 10 m revealed clay/leachate, clay, and clayey sand. The depth of 20 to 50 m along the profile between 40 and 100 m reveals the same subsurface lithologies. At a lateral distance of 115 m within depth of 10 m, a small volume of leachate is shown to have a resistivity value of <11 Ωm. At horizontal distances of 100 to 180 m with a depth of 50 m from the surface composes of clay/leachate, clay, and clayey sand. Across the profile reveals the presence of leachate. The leachate is distinctive at the depth of 8 to 18 m at lateral distance of

55 to 90 m and also distinctive at depth of 10 to 22 m at horizontal distance of 155 to 180 m across the profile having very low resistivity values ranging from 6 to 8 Ωm.

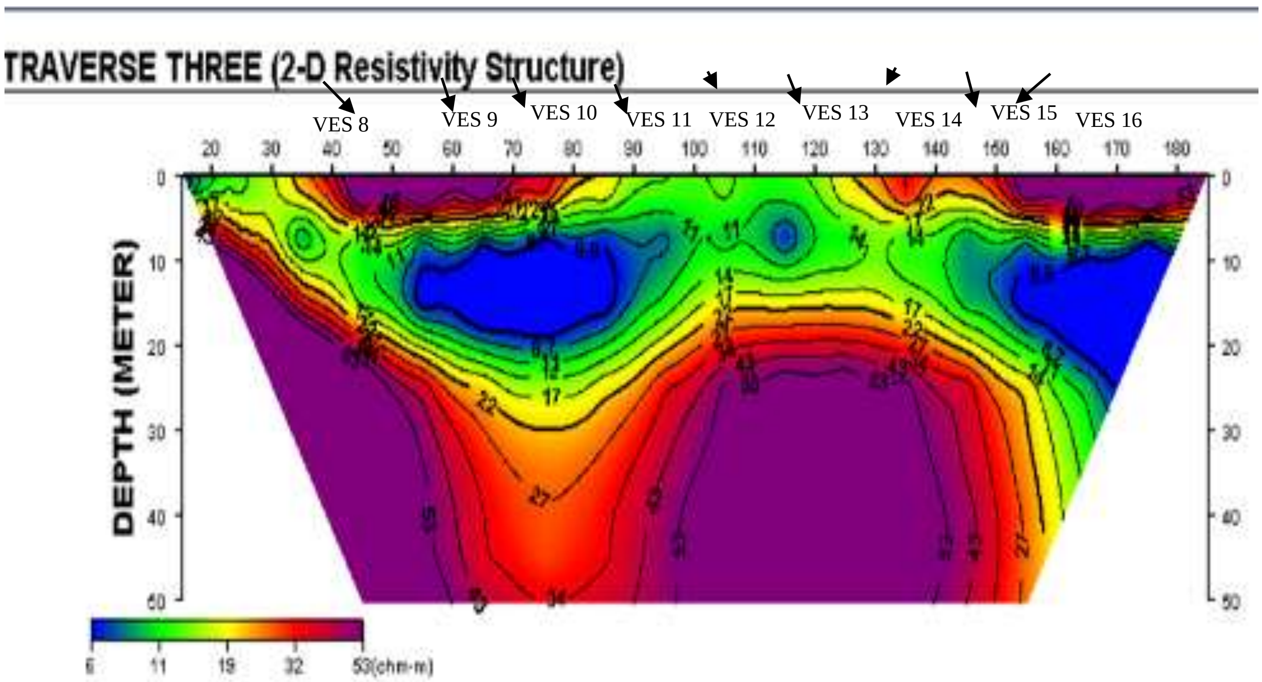

Figure 5c: *2D Resistivity Structure (Traverse Three)*

2-D Resistivity Section along Traverse Four

A spread of 150 m was surveyed and a depth of 30 m was probed with resistivity values ranging from 24 to 137 Ωm (Figure 6d). The VES 17, 18, 19, 20, 21, 22, 23, 24, and 25 were along the 2D profile at horizontal distances of 35, 45, 55, 65, 85, 100, 115, 130, and 145 m respectively. There is apparent contamination of the topsoil by leachate as shown by a low resistivity value of <24 Ωm at a lateral distance of 60 to 140 m with a depth from the ground surface to 4 m. The depth of 20 m from the ground surface is indicative of clay and clayey sand, sandy clay and sand having a resistivity value ranging from 25 to 138 Ωm across the profile. The depth from 20 to 30 m signifies clayey sand, sandy clay as well as sand with resistivity in the range of 78 to 138 Ωm across the profile. The sand is distinctive at the depth of 0 to 20 m at horizontal distance of 0 to 30 m and it is also distinctive at the depth of 18 m to 30 m at a lateral distance of 105 to 130 m across the profile having resistivity values ranging between 114 and 138 Ωm.

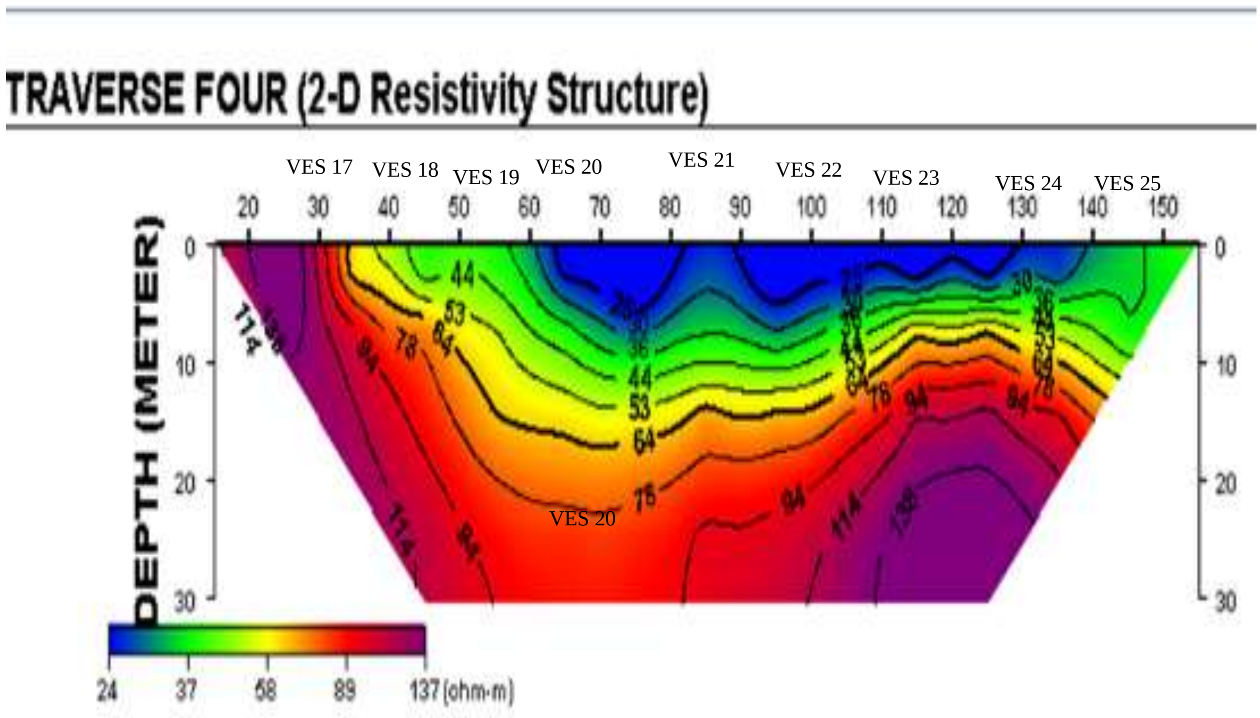

Figure 5d: *2D Resistivity Structure (Traverse four)*

Results of Aquifer Protective Capacity

The longitudinal conductance map displaying the overburden protective capacity of the study area is shown in Figure 6a.

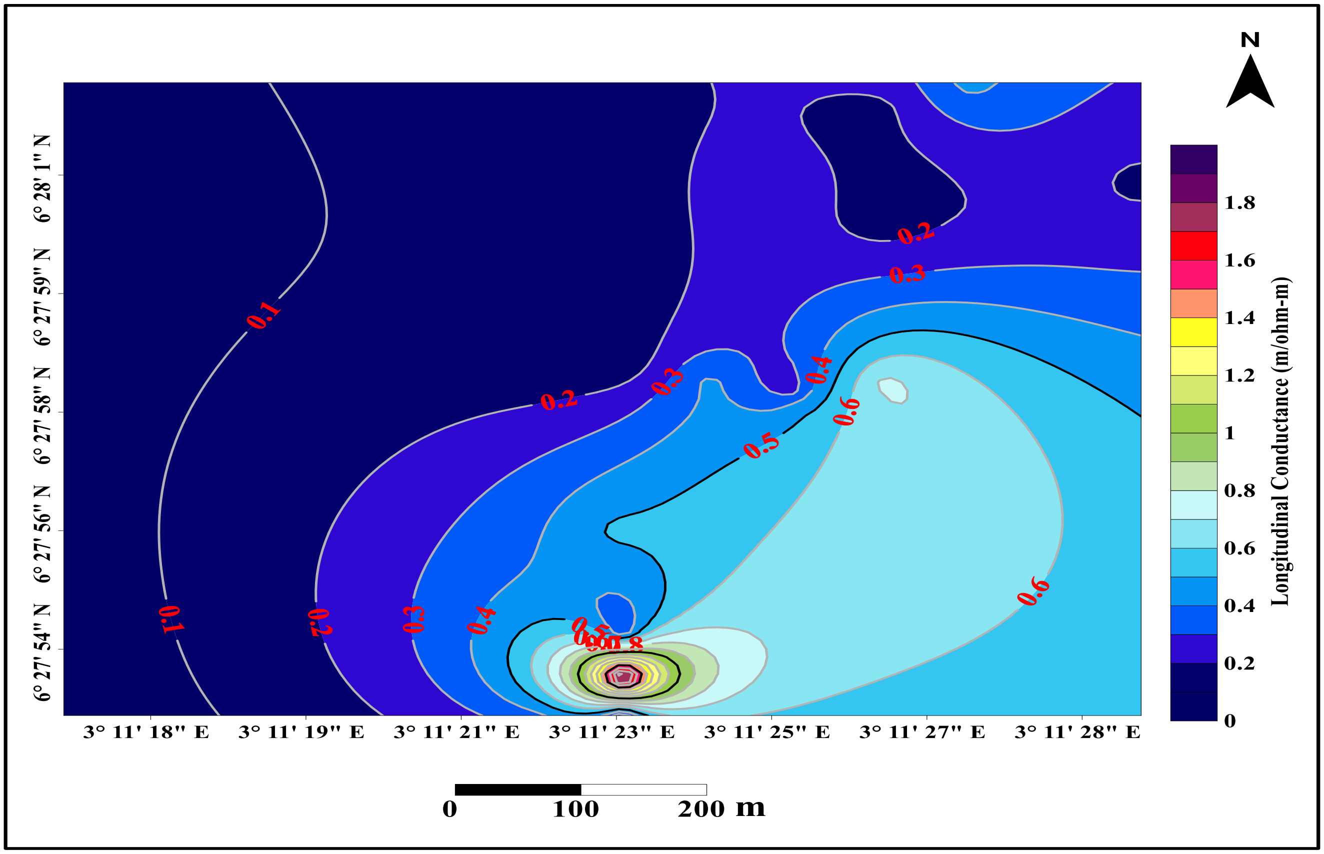

Figure 6a*:* Longitudinal Conductance Map

The study map is divided into four cardinal directions (NW, SW, SE, and NE) for easy discussion, using the longitudinal unit conductance values and employing the protective capacity rating model (Table 1). The Northwest region of the study area has longitudinal conductance values in the range of (0.1– 0.2 mho), thus depicting weak to moderate protective capacity in the area. The Southwest region depicts an area with poor to good protective capacity having longitudinal conductance values in the range of (0.05 – 2.0 mho). The Southeast region depicts an area with moderate to good protective capacity that have longitudinal conductance values in the range of (0.5 – 0.8 mho). The good aquifer protective capacity zones have higher attenuation property on contaminated fluids, such zones disallow flow-in of contamination thus are apparently safe. The Northeast region has longitudinal conductance values within the range of 0.2 – 0.4 mho, depicting the area to have aquifer underlain with moderate protective capacity.

The longitudinal conductance (Table 3), revealed that the aquifer of most part of the VES zones is moderately protected, covering 52% of the study area; VES 1, 2, 3, 5, 10, 11, 14, 16, 17, 18, 19 and 20. However, 12% of the study area have good aquifers protective capacity; VES 12, 13, and 21. 36% of the study area have poor to weak protective capacity; VES 4, 6, 7, 8, 9, 22, 23, and 24, making these part of the study area extremely vulnerable, hence were prone to contamination by leachate if the pollution was present.

Table 3: Summary of Longitudinal conductance and Protective capacity of the Study Area

VES	**Layers**	**Resistivity ρ (Ωm)**	**Thickness h(m)**	**Coordinates**	**Longitudinal conductance h_i/ρ_i (mho)**	**Protective capacity**
1	1	106.3	0.5	6.46680˚N 3.19093˚E	0.217983	Moderate
	2	115.6	1.2			
	3	26.1	3.0			
	4	200.1	17.6			
	5	16.8	---			
2	1	258.6	0.8	6.46686˚N		
	2	44.6	6.5			
	3	161.6	14.8	3.19028˚E	0.240417	Moderate
	4	174.1	---			
3	1	31.1	0.9	6.46689˚N		
	2	46.9	1.7			
	3	70.2	14.9	3.19028˚E	0.277437	Moderate
	4	137.0	---			
4	1	13.3	0.9	6.46697˚N		Weak
	2	38.7	1.8			
	3	94.1	6.0	3.19139˚N	0.177942	
	4	133.3	---			
5	1	25.5	1.0	6.46739˚N		
	2	61.7	0.7			
	3	15.0	0.5	3.19083˚E	0.436835	Moderate
	4	25.5	9.0			
	5	278.5	---			
6	1	31.6	0.8	6.46728˚N		
	2	35.5	1.6			
	3	85.1	8.8	3.19056˚E	0.173794	Weak
	4	160.9	---			
7	1	16.6	1.0	6.46684˚N		
	2	83.2	2.3			
	3	345.2	12.2	3.19056˚E	0.123227	Weak
	4	62.4	---			
8	1	62.2	0.9	6.46711 ˚N		
	2	48.1	3.3			
	3	78.2	7.0	3.18972˚E	0.172591	Weak
	4	434.8	---			
9	1	76.8	0.9			

	2	34.0	3.7	6.46472˚N		
	3	404.9	22.4			
	4	19.8	---	3.18972˚E	0.175864	Weak
10	1	80.7	0.9	6.46472˚N		
	2	40.7	1.3			
	3	29.2	9.5	3.18944˚E	0.368436	Moderate
	4	212.2	---			
11	1	75.6	0.3	6.46472˚N		
	2	59.4	2.5			
	3	9.4	4.4	3.18972˚E	0.553283	Moderate
	4	214.6	8.4			
	5	7.4	---			
12	1	39.2	0.8	6.46472˚N		
	2	116.4	0.6			
	3	24.7	5.5	3.18944˚E	1.740772	Good
	4	6.7	10.0			
	5	67.8	---			
13	1	53.7	0.5	6.46488˚N		
	2	59.3	4.2			
	3	3.0	1.1	3.18972˚E	2.007013	Good
	4	19.1	29.8			
	5	68.6	---			
14	1	41.4	0.9	6.46506˚N		
	2	172.0	0.6			
	3	152.9	3.1	3.18972˚E	0.322989	Moderate
	4	50.9	12.4			
	5	451.7	15.3			
	6	21.3	---			
15	1	42.4	0.9	6.46514˚N	0.050938	Poor
	2	406.5	2.8			
	3	538.9	12.3	3.18792˚E		
	4	150.4	---			
	1	83.0	0.7	6.46603˚N		
	2	54.9	3.7			
16	3	46.7	17.3	3.19028˚E	0.446278	Moderate
	4	237.0	---			
	1	104.3	0.8	6.46608˚N		
	2	48.8	2.0			
17	3	54.6	12.0	3.19027˚E	0.268434	Moderate
	4	116.6	---			
	1	176.2	0.6	6.46613˚N		
	2	97.5	2.0			
18	3	9.7	2.0	3.19027˚E	0.230103	Moderate
	4	104.5	---			
	1	53.9	1.1	6.46613˚N	0.314521	Moderate
	2	93.8	1.4			
19	3	19.7	5.5	3.19028˚E		
	4	116.5	---			
	1	127.9	0.9	6.46613˚N	0.422715	Moderate
	2	65.7	1.9			
	3	28.7	11.1			

20	4	139.6	---	3.19000˚E		
21	1	48.1	0.7	6.46613˚N	0.724000	Good
	2	56.1	39.8			
	3	149.0	---	3.19056˚E		
22	1	63.0	0.8	6.46622˚N		
	2	116.8	2.7			
	3	378.2	28.3	3.18972˚E	0.110642	Weak
	4	70.6	---			
23	1	71.7	0.7	6.46619˚N		
	2	39.3	2.3			
	3	255.4	3.9	3.18944˚E	0.141558	Weak
	4	379.3	22.0			
	5	78.0	----			
24	1	120.0	0.4	6.46625˚N	0.149166	Weak
	2	26.9	3.2			
	3	372.1	10.0	3.18947˚E		
	4	20.7	---			
25	1	37.8	0.6	6.46550˚N	0.519075	Moderate
	2	113.1	2.2	3.18969˚E		

The aquifer resistivity map of Figure 6b shows the aquifer zones in the study area based on the resistivity values. The resistivity variation column indicates low to high aquifer resistivity. The VES with high resistivity values ranging from 250 to 460 Ωm depict aquifers possibly underlain with moderate to good overburden protective capacity, while the resistivity values ranging from 100 to 250 Ωm depict aquifer zones with possible overburden material thickness that could over time, allow infiltration of contaminant loading.

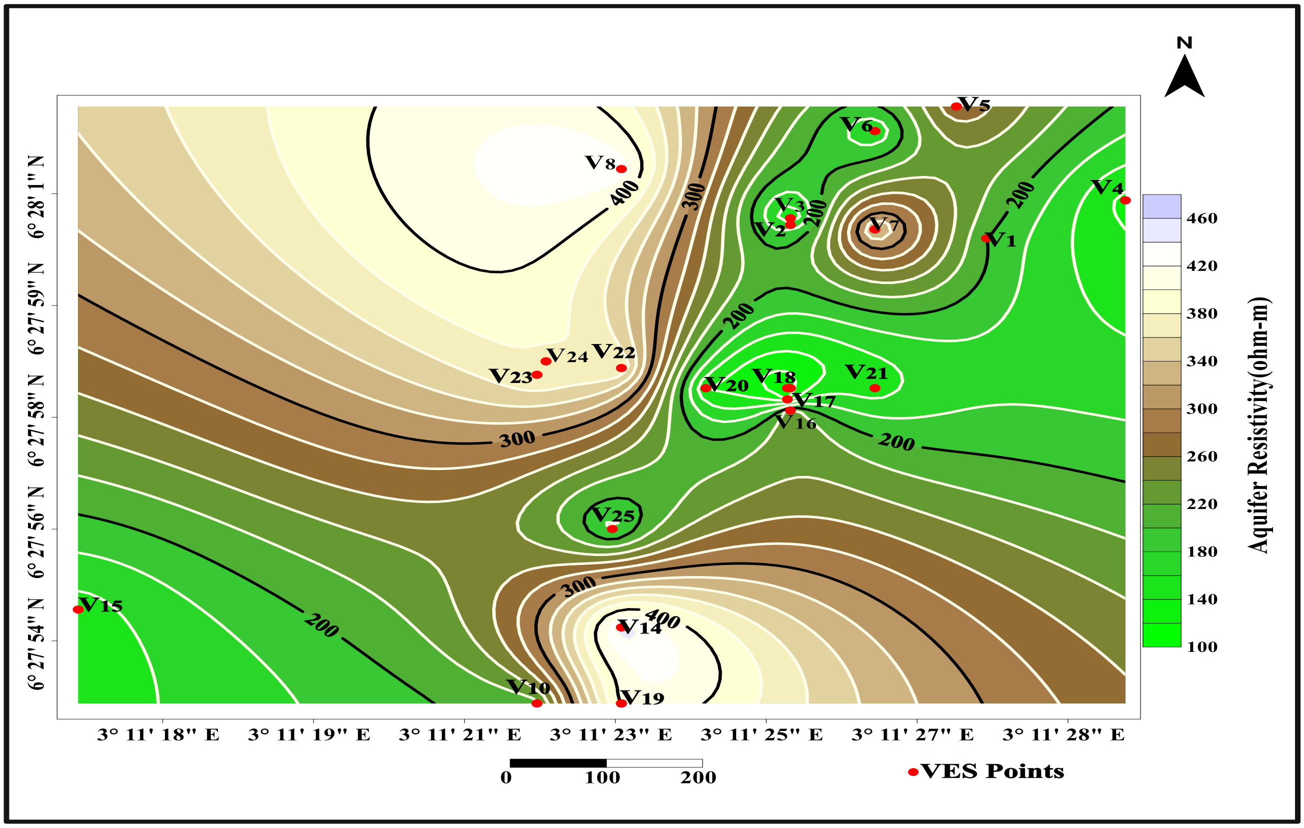

Figure 6b: *Aquifer Resistivity Map*

4. CONCLUSION

Geophysical investigation using VES and 2D electrical resistivity imaging techniques has been conducted at Cassidy, Okokomaiko, Lagos-Badagary expressway, Ojo Lagos State. The investigation was conducted to assess the extent of leachate migration and the aquifer protective capacity.

Three to six geoelectric layers were delineated which correspond to the topsoil, clay, sandy clay, clayey sand, sand and clay/leachate. The 2D resistivity structures reveal the lateral and vertical subsurface information with resistivity values ranging from 6 to 137 Ωm. The resistivity values correspond to the six delineated geoelectric layers. The 2D resistivity structure, therefore, complements the vertical electrical sounding results.

Three distinct aquifer protective capacity zones were delineated, namely poor, weak, moderate, and good protective capacity. **36%** of the study zones, comprising VES 4, 6, 7, 8, 9, 22, 23, and 24 have poor and weak protective capacity, while, **52%** which includes VES 1, 2, 3, 5, 10, 11, 14, 16, 17, 18, 19 and 20 possessed moderate protective capacity. However, **12%** of the study area comprises aquifers in VES 12, 13, and 21 that have good protective capacity.

Poor and weak aquifer protective capacity zones are known to be very vulnerable to contamination because of high porosity, while areas of moderate aquifer protective capacity zones are less vulnerable to contamination. Zones with good or excellent aquifer protective capacity have higher attenuation properties on contaminated fluids as a result, they are apparently safe.

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